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Article *in* Northwestern Naturalist · September 2007

DOI: 10.1898/1051-1733(2007)88[73:ECODHI]2.0.CO;2

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NORTHWESTERN NATURALIST 88:73–84 AUTUMN 2007

ECOLOGICAL CLASSIFICATION OF DEER HABITAT IN THE TONGASS NATIONAL FOREST, ALASKA

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ABSTRACT—Ecologists and wildlife managers often rely on habitat classifications that are based on existing resource inventories and expert opinion. In the Tongass National Forest of southeastern Alaska, as in many managed ecosystems, forest types are defined primarily on the basis of structural characteristics, like tree stocking, size, and composition. While useful in management for timber production, this method of identifying forest types produces a classification with limited relevance to wildlife management. Sitka Black-tailed Deer (*Odocoileus hemionus sitkensis*) are an important component of the ecology and economy of this region. We classified forests by applying cluster analysis to a suite of 12 environmental variables of ecological importance to deer, sampled on a 180-km^2 study area. The analysis identified an ecological typology that consisted of 3 old- and 5 2nd-growth forest types and 1 non-forest cover type. We found that the structural classification currently in use confounded post-logging categories of differing value to deer and categorized old-growth forests in ways that may not relate clearly to deer ecology. Our method makes it possible to produce an ecological classification that incorporates information from an existing resource database, facilitating the integration of the 2 typologies. Such ecologically based habitat classifications are valuable tools for the conservation of animal species, especially those inhabiting intensively managed ecosystems.

Key words: Sitka Black-tailed Deer, *Odocoileus hemionus,* cluster analysis, classification, habitat, coastal temperate rainforest, Alaska

Efforts to conserve animal species typically involve a significant focus on habitat management. For example, an important component of population viability analysis is modeling the influence of habitat and land-use changes on demography (Boyce 1992). In wildlife ecology, species interactions with habitat are a key area of research, and the way habitats are defined can have significant effects on quantitative measures of habitat selection (O'Neil and others 1995; Knight and Morris 1996; Mumby and Harborne 1999; Lindenmayer and others 2003). However, this issue typically does not receive much attention in such studies. A habitat classification divides an animal's environment (a continuum) into discrete subsets. This division of continuous ecological gradients into discrete types is particularly useful in management and conservation plans, which usually develop distinct prescriptions for different habitat categories.

The use of forest typologies based on overstory structural variables is a common feature of forest management, which requires a set of categories on which to build strategies of harvest, protection, and treatment. These systems of classification have their basis in features that may not relate directly to habitat value for a given wildlife focal-species, and, when used to define habitat types for that animal, may not be useful in the development of effective conservation strategies. In the Tongass National Forest of southeastern Alaska, management for multiple uses, including timber production,

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has occurred since the 1950s, and management prescriptions are based on a structural, ''timber type'' classification (USFS 1997). Under this management paradigm, concern has grown for the maintenance of biodiversity and wildlife value in the Tongass and elsewhere in the coastal temperate rainforest (Wallmo and Schoen 1980; Harris 1984; Schoen and Kirchhoff 1990; Lomolino and Perault 2000; Hall 2001; Person 2001; Farmer and others 2006). Sitka Black-tailed Deer (*Odocoileus hemionus sitkensis*) are a major focus of concern in the Tongass (Hanley 1993). These large herbivores are of particular concern because they are the most important mammal for subsistence and recreational hunters and are also the principal prey of wolves in the region (Kohira and Rexstad 1997; Person 2001). As a result of their economic and ecological importance, it has been suggested that deer be used as an ecological indicator species for management plans in the coastal rainforest ecosystem (Hanley 1993).

In coastal southeastern Alaska, Sitka Black-tailed Deer are strongly associated with old-growth forests where they can find abundant, nutritious forage throughout the year (Schoen and Kirchhoff 1990), although this association is less pronounced where snowfall is light (Yeo and Peek 1992). The cumulative loss of old-growth forest due to clear-cut logging is cause for conservation concern with respect to deer and other old-growth associates. During snow-free periods, young clearcuts provide abundant forage for deer but, as succession advances, even-aged 2nd-growth stands develop, shading out most understory plants (Alaback 1982). The magnitude of the effect on deer, mediated through plant composition and biomass, varies with seral stage (Alaback 1982), soil moisture (Hanley and Brady 1997), site productivity (Billings and Wheeler 1979), canopy cover (Martin 1989), and disturbance history (Hanley and Brady 1997; Kramer and others 2001). Snow interception, which alters seasonal availability of forage for deer, is affected by overstory attributes such as canopy mass, tree height, and crown closure (Hanley and Rose 1987; Kirchhoff and Schoen 1987). Additionally, the nutritional quality of available forage varies with seral stage, season, and site conditions (Billings and Wheeler 1979; Van Horne and others 1988). Forage quality as well as forage abundance plays an essential role in deer survival, productivity, and ecological carrying capacity in southeastern Alaska (Hanley and others 1989; Parker and others 1999; Farmer and others 2006).

The current forest management classification is based on structural aspects of the forest overstory and may not reflect forest divisions ecologically meaningful to deer and other wildlife. Conversely, a classification based solely on deer ecology would be of little value for timber management without some link to the structural attributes that are important to silviculture. Our previous research has demonstrated that vital rates of deer vary in relation to discrete classes of vegetative cover (Farmer and others 2006). This suggests that the development of a forest classification that uses ecological and structural variables to derive discrete classes will be useful for its ability to capture variation that is important to deer as well as for its accessibility to forest managers.

Our objective was to develop a forest classification that could satisfy the needs of deer managers for ecologically meaningful categories while maintaining utility to forest managers. To accomplish this, we used cluster analysis to classify forests based on understory characteristics reflecting the availability of forage for deer and overstory characteristics amenable to remote sensing. We then quantified the biomass of several important categories of deer forage in the resulting categories as a means of comparing their relative value to deer as foraging habitat.

METHODS

Study Area

The study was conducted on Heceta Island (6,183,676 N, 593,221 E, zone 8N), which is typical in productivity and logging history of southeastern Alaska. Southeastern Alaska encompasses approximately 11 million ha, most of it within the Tongass National Forest. Heceta Island, located off the west coast of Prince of Wales Island, is approximately 180 km^2 in area with 100 km of coastline and elevations ranging from 0 to 915 m. The climate has a strong maritime influence, with cool, wet winters during which there is little snow accumulation below approximately 150 m. At Ketchikan, Alaska, the nearest weather station for which there are long-term climate records, mean monthly precipitation ranges from 16.3 (May) to 51.5 cm (October) with a mean annual total of 349 cm.

Mean monthly temperatures range from 0.8°C in January to 14.6°C in August (NOAA 2002).

Heceta Island supports productive coniferous forest growth, dominated by Western Hemlock (*Tsuga heterophylla*), and Sitka Spruce (*Picea sitchensis*), with lesser amounts of Western Red Cedar (*Thuja plicata*), Alaska Yellow Cedar (*Chamaecyparis nootkatensis*), Mountain Hemlock (*Tsuga mertensiana*), and Shore Pine (*Pinus contorta contorta*). Common shrubs include several species of Blueberry and Huckleberry (*Vaccinium* spp.), Salmonberry (*Rubus spectabilis*), and Devil's Club (*Oplopanax horridus*). Ground vegetation is dominated by evergreen forbs (for example, *Cornus canadensis, Coptis aspleniifolia*), deciduous forbs (for example, *Maianthemum dilatatum, Lysichiton americanum*), ferns (*Dryopteris dilatata, Gymnocarpium dryopteris*), and bryophytes (*Sphagnum* spp., *Hylocomium* spp., *Rhytidiadelphus* spp.).

Even-aged timber harvest on the study area began about 1926, with the majority of logging occurring between 1970 and 1985. This logging history left Heceta Island with a broad age range of seral forests ideal for examining issues related to stand age and structure. By 1996, 42% of the productive forest on the island had been cut (USFS 1996). At the time of the study, 65% of the 2nd-growth forest was <26 y old and the balance of logged forestland was in pole timber or young sawtimber stages (26 to 150 y old).

Forest Composition

Vegetation data were collected at 70 randomly selected sample points throughout the study area between 20 June and 20 August, 1996 and 1997. Sample points were identified by overlaying a 1-km × 1-km grid on a map of the island and using a random number generator to select 70 grid nodes. The number of grid nodes visited was determined by the availability of volunteer labor for the field crew. High-elevation meadows cover <1% of the island surface and were missed by the initial assignment of sample points, so 2 of the original points were selected at random and reassigned to these meadows to enable us to characterize their forage cover and biomass.

From each sample point, six 0.2-ha circular plots were placed at 100-m intervals along a randomly selected compass bearing. This design produced 420 plots, but 26 could not be sampled due to dangerous terrain, resulting in a total of 394 sampled plots. Sampling was conducted in a nested plot design; variables indicative of general site quality were measured for the entire 0.2-ha plot, and forage variables for which we estimated biomass were measured on six 4-m^2 or 1-m^2 quadrats arrayed at 10-m intervals within the plot along the transect axis. Variables measured at the scale of the 0.2-ha plot were site elevation, aspect, stand age, average tree height, tree basal area, visibility distance, and percentage ground cover (Daubenmire 1959) of Devil's Club, Rusty Menziesia (*Menziesia ferruginea*), Salal (*Gaultheria shallon*), Salmonberry, Shield Fern (*D. dilatata*), and Skunk Cabbage (*L. americanum*). Tree basal area was measured using a relaskop on variable area plots (Grosenbaugh 1952) at the center of each 0.2-ha plot. Visibility distance was measured as the straight-line distance along the transect bearing at which a 2-m tall range pole placed in the center of the plot was totally obscured from view by intervening vegetation at a viewing height of 1 m.

Variables measured within each 4-m^2 quadrat were percentage ground cover of Red Huckleberry (*V. parvifolium*) and Alaska and Ovalleaf Blueberry (*V. alaskensis* and *V. ovalifolium*), total shrub cover below 1.5 m in height (available shrubs), and tree basal area. On 1-m^2 quadrats, we measured ground cover of evergreen and deciduous forbs. Quadrat sizes were chosen based on the area typically covered by 1 individual plant of each forage category; larger quadrats were chosen for larger forage categories. We chose to measure percentage ground cover of forage plants because this provides foraging deer a readily visible index to available biomass in a patch. We averaged values of all variables across quadrats for each plot and performed analyses at the plot level.

Hierarchical agglomerative cluster analysis (Statistica 6.0, Statsoft, Inc., Tulsa, OK) was used to identify forest cover types. Based on examination of descriptive statistics, the data were first aggregated into 5-y age groups (2nd-growth) and 58.3-m^3/ha (10 mmbf/ac) timber volume groups (old-growth). Our goal was to aggregate the original 394 plots into the largest possible homogeneous groups prior to classification. Such *a priori* assignment to groups is common in cluster analysis and greatly simplifies the interpretation of results for large numbers of sample units. The 2 grouping factors we chose are the basis of the structural classification used in the region and provide a means of linking our ecological classification to existing management categories. These factors also strongly influence the light regime of a stand, thereby influencing the understory (Alaback 1982; Hanley and Brady 1997).

Variables used in the cluster analysis were visibility distance and percentage ground cover of evergreen forbs, deciduous forbs, Shield Fern, Salal, Skunk Cabbage, Rusty Menziesia, Devil's Club, Salmonberry, Red Huckleberry, combined Alaska and Oval-leaf Blueberry, and available shrubs (below 1.5 m). We did not use overstory variables for the cluster analysis because they had been used to define groups entering the analysis. Homogeneous clusters in the data were identified based on a multivariate dissimilarity index (Euclidean distance) in conjunction with a weighted pair group method using arithmetic averages (WPGMA). We chose WPGMA for the analysis because sample sizes varied widely ($2 \leq n \leq 77$), and this linkage method is most appropriate for ecological data from groups of unequal size (Legendre and Legendre 1998).

Hierarchical agglomerative clustering produces a hierarchy of categories in which 1 extreme is a category for every case and the other extreme is a single category containing all cases. To identify the most ecologically meaningful level of clustering, we applied pairwise discriminant function analysis (DFA) to nearest-neighbor groups of clusters in a hierarchical fashion. In this procedure, each of the original forest cover groups was compared to its nearest neighbor to test the null hypothesis that both groups belonged to the same cluster. If no significant discriminant function ($\alpha = 0.05$) could be created for the pair, they were considered members of a single cluster formed at the next level of the dendrogram. In this fashion, clusters joined at progressively larger linkage distances were examined until significant discriminant functions could be derived. Clusters were considered validated if a significant discriminant function separated them from their nearest-neighboring cluster. Rather than a strict test of hypothesis, we interpreted *P*-values of discriminant functions at each level of clustering as evidence of the magnitude of discontinuity among clusters (lower *P*-values indicated stronger discontinuity).

Biomass Estimation

We used empirically derived regression equations (Farmer and others 2006) to predict edible biomass (kg/ha) from percentage ground cover estimates of *Vaccinium* shrubs (Dry Wt. = 0.69[% cover]; $r^2 = 0.95$, $P < 0.001$), evergreen forbs (Dry Wt. = 1.08[% cover]; $r^2 = 0.93$, $P < 0.001$) and deciduous forbs (Dry Wt. = 0.12[% cover] + 0.003[% cover]^2; $r^2 = 0.99$, $P < 0.001$) for each plot in the vegetation study. These 3 categories comprise the most important forage items for Sitka Black-tailed Deer in the region (Hanley and McKendrick 1985; Hanley and others 1989) and provide a means of relating our cover types to previous studies of forage biomass and to existing forest classifications. To compare our ecologically based categories to structurally based categories, we calculated percentage deviations between the categories for the understory variables evergreen forb biomass, *Vaccinium* shrub biomass, and visibility distance.

RESULTS

Forest Composition

Pairwise DFA provided strong support for a discontinuity in the hierarchical dendrogram corresponding to a linkage distance of 3.8, which produced 9 forest cover types (Table 1, Fig. 1). Six of 8 *P*-values for the DFA at this level were ≤ 0.01, and all were ≤ 0.05 (Fig. 2).

Univariate comparisons of individual habitat variables revealed clear differences among the cover types (Tables 2 and 3). Such differences do not automatically follow from comparisons among clusters because cluster analysis maximizes inter-group distances in multivariate, not univariate, space. Ground cover of understory vegetation showed a general pattern of decrease with age in even-aged seres (shrub-sapling > transitional > stem exclusion > closed-canopy), except in thinned stands. The response of vegetation to pre-commercial thinning was evident in the high ground coverages of shrubs (60.1%), Salmonberry (21.4%), and Rusty Menziesia (12.1%), the increased tree height (10.0 m), and the increased representation of Spruce (62.7%) in thinned transitional clearcuts. Old-growth forests were characterized by intermediate coverages of most forage species (Table 2). Riparian Spruce old-growth forests were distinctive from other habitat

TABLE 1. Descriptions of cover types identified in southeastern Alaska by cluster analysis on 12 understory variables.

Non-forest—predominantly heath or bog-like muskegs with ≤10% canopy cover and no measurable timber volume.
Open-canopy old-growth—primarily uneven aged Hemlock-Cedar forest <58.3 m^3/ha gross timber volume.
Coarse-canopy old-growth—primarily uneven-aged Hemlock-Spruce-Cedar forest, ≥58.3 m^2/ha gross timber volume.
Riparian Spruce old-growth—relatively small stands of Hemlock-Spruce forest 291.5 to 349.8 m^2/ha gross timber volume situated on productive alluvial soils associated with some riparian zones; relatively closed canopy resulting in less-developed understory than coarse-canopy old-growth.
Shrub-sapling—even-aged clearcuts ≤19 y post-logging at mid-point (1998) of our study; canopy completely removed, conifer regeneration at seedling to large sapling stage.
Transitional—older clearcuts 20 to 39 y post-logging at mid-point (1998) of our study; conifer regeneration at large sapling stage; canopy beginning to close over reducing amount of light reaching forest floor; shrub and forb biomass patchily distributed.
Thinned transitional—transitional clearcuts silviculturally thinned approximately 10 y prior to sampling; canopy more open than transitional 2nd-growth resulting in increased shrub growth.
Stem exclusion—Spruce-dominated clearcuts, 40 to 44 y post-logging at the mid-point (1998) of our study; dense canopy precluding light penetration resulting in depauperate understory.
Closed-canopy 2nd-growth—Hemlock-Spruce-dominated clearcuts, 45 to >70 y post-logging at the mid-point (1998) of our study; beginning to self-thin; dense canopy precluding light penetration resulting in depauperate understory.

types due to their high proportion of Spruce (30.1%) in the overstory, mean timber volume (327.8 m^3/ha), and understory Devil's Club (20.0%) and Shield Fern (6.0%; Tables 2 and 3). Stem exclusion and closed-canopy 2nd-growth categories were characterized by depauperate understories and productive overstories with higher proportions of Spruce than existing old-growth forests (Tables 2 and 3). Salal was found only in old-growth cover types, primarily those with low to moderate timber volumes.

Visibility distance mirrored the pattern of shrub abundance (Table 2). Intermediate visibility distances were recorded in open-canopy, coarse-canopy, and riparian Spruce old-growth categories and stem exclusion 2nd-growth stands. Examination of descriptive statistics for the stem exclusion category indicated that its visibility distance was derived primarily from the high stem density of trees rather than from shrub cover, as was the case in old-growth habitats. Similarity on this variable largely accounted for the close clustering of stem exclusion with coarse-canopy old-growth stands. The shortest visibility distance measurements were found in shrub-sapling, transitional, and thinned transitional cover types, which have high shrub covers and conifer stem densities.

Biomass Estimation

Biomass of deciduous forbs was higher in old-growth (9.0 to 19.9 kg/ha) forest categories than in regenerating clear-cut stands (0.1 to 8.6 kg/ha). Conversely, evergreen forbs reached higher biomass (290.8 kg/ha) in shrub-sapling 2nd-growth than in any other cover type (Table 2). Biomass of both types of forbs declined with increasing 2nd-growth stand age, but thinned transitional stands supported higher biomasses than other stands of similar age. Stem exclusion and closed-canopy 2nd-growth forest categories supported extremely low biomasses of this forage type (for example, closed-canopy, 13.0 kg/ha). Total forb biomasses in old-growth forests were lower than in the shrub-sapling cover type, but higher than those in even-aged seres ≥20 y post-logging (Table 2). Biomass of *Vaccinium* shrubs (current annual growth) also was highest in shrub-sapling (67.0 kg/ha) and thinned transitional (71.7 kg/ha), decreasing with age in 2nd-growth categories and reaching intermediate levels in old-growth forests (Table 2).

Percentage deviations between structurally based categories and our corresponding deer cover types for 3 understory variables (visibility distance, evergreen forb biomass, and *Vaccinium* shrub biomass), revealed differences of up to 200% between the typologies on these important plant community characteristics (Fig. 3).

DISCUSSION

Application of cluster analysis to a continuum of sample plots from across our large (180 km^2) study area yielded a novel habitat classification for deer in the northern coastal temperate rainforest. Cluster analysis has previously been used to develop a habitat classification for White-tailed Deer (*Odocoileus virgi-*

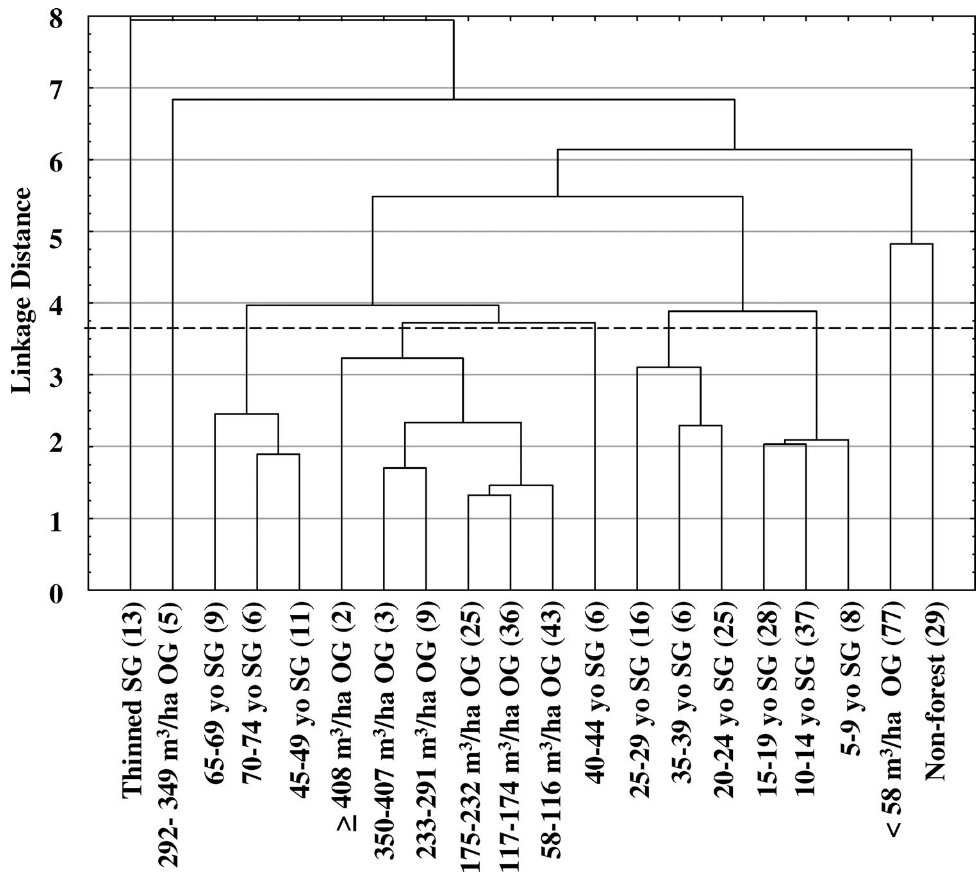

FIGURE 1. Hierarchical cluster analysis dendrogram produced by weighted pair group method using arithmetic averages (WPGMA). Dashed line indicates significant discrimination based on pairwise DFA of understory variables. Sample sizes are indicated after group names. OG = old-growth, and SG = 2nd-growth.

nianus; Stocker and others 1977). However, this classification was for deer inhabiting a very different ecosystem and relied on qualitative validation of clusters. The only quantitatively validated habitat classification we have found for a deer species was developed for Caribou (*Rangifer tarandus*) in the Northwest Territories of Canada (Thompson and Klassen 1980). The ecological differences between Caribou and members of the genus *Odocoileus* as well as those between the 2 ecosystems highlight the need for habitat typologies to be specific to species and ecosystems.

Predicting the effects of forestry practices on deer has thus far relied on carrying capacity and habitat suitability index (HSI) modeling in southeastern Alaska (Suring and others 1990; Hanley and Rogers 1989). These models used a typology derived largely from overstory structural attributes in order to integrate with resource management planning needs. The habitat classification we developed for deer based on understory attributes suggests that the structure-dominated typology combines distinct 2nd-growth cover types for deer, subdivides a relatively homogeneous old-growth forest type, and fails to identify a distinct old-growth forest type.

Our analysis shows that, relative to deer foraging ecology, discontinuities occur in the midst of several structurally based management categories (Table 4 and Fig. 3). This means that 2 or more distinct cover types for deer are managed as though they are the same under the current structural typology. For example, the current size class 2 category (2nd-growth

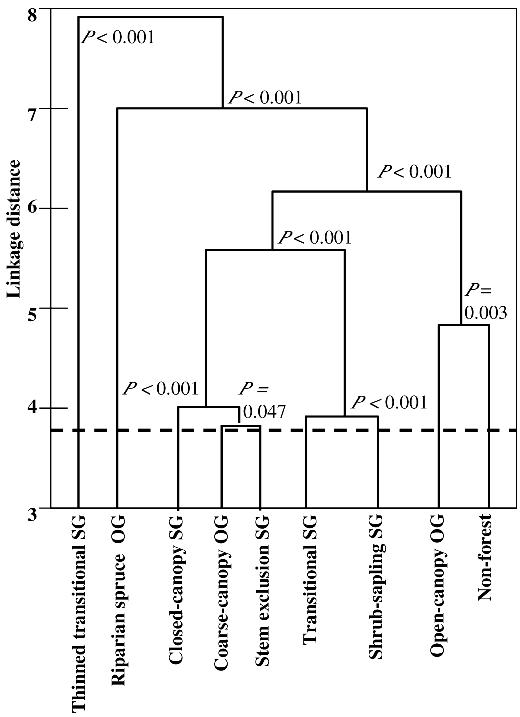

FIGURE 2. Weighted pair group method using arithmetic averages (WPGMA) dendrogram showing final clusters validated by discriminant analysis on understory variables. The dendrogram depicts the upper portion of Fig. 1, showing clusters joined at linkage distances above 3.0. Dashed line indicates the linkage distance at which clusters were validated. OG = old-growth, and SG = 2nd-growth. P-values are shown for DFA between adjacent clusters.

26 to 75 y post-logging) includes 4 distinct 2nd-growth cover types for deer (transitional, thinned transitional, stem exclusion, and closed-canopy). Each of these deer cover types differs from size class 2 by $\geq$1 SE on $\geq$1 understory variable (Fig. 3). Management based on this silvicultural category could prove detrimental to deer populations if, for example, large areas are converted to stem exclusion stands based on the assumption that forb and shrub biomasses will be the same as the mean value for size class 2.

Conversely, our habitat classification suggests that only 3 old-growth forest cover types are distinctive to foraging deer in terms of understory composition. The current silvicultural typology defines a similar number of categories, but uses break points that are arbitrary with respect to deer. This leads to management for old-growth categories differing little from one another in important deer forage variables and does not recognize that riparian Spruce stands are unique (Tables 1, 2 and Fig. 3). With the exception of riparian Spruce, old-growth stands in the timber volume categories from 58 to >408 m^3/ha (10 to 70 mmbf/ac) are heterogeneous to a human observer, but this heterogeneity is primarily along axes (overstory characteristics) and over spatial scales that do not directly reflect forage availability. Our analysis shows that these old-growth types are equivalent at the scale of our measurements in terms of average forage species abundance and biomass. Forage biomass varies through space, but it varies on a small scale (gap phase) that does not correlate with the obvious differences in timber volume among productive old-growth stands. While this finding may tempt some managers to treat all coarse-canopy old-growth forests as equivalent and therefore interchangeable with respect to deer management, we caution that it indicates a need for future analyses to be carried out at a finer-grained spatial scale than is possible with our data.

Shrub-sapling stands support higher biomass of valuable forage plants than older seral stands, but they inevitably age into these less-productive cover types. The forest cover classification we have discussed is based on summer forage availability and implicitly assumes that winter does not alter relative forage availability among the habitats. This assumption is approximately correct for typical years on our study area. However, periodic severe snowfalls as well as typical snow accumulations in northern parts of the region may limit the availability of forage biomass in shrub-sapling stands during winter. If management for severe (and hence probably limiting) snowfall in the region is desirable, then we recommend use of a classification that incorporates overstory as well as understory variables (Appendix). This classification was developed using the methodology we have described and places emphasis on differences among cover types that directly affect snow interception, such as basal area and timber volume (Kirchhoff and Schoen 1987). A potential drawback of such a classification is that the large number of forest types it comprises may prove difficult to use in a management context.

TABLE 2. Understory characteristics, $\bar{X}$ ($s_{\bar{x}}$), of deer cover types in southeastern Alaska. Abbreviations indicate the following habitat types (n): SS = shrub-sapling 2nd-growth (73); TT = thinned transitional 2nd-growth (13); TS = transitional 2nd-growth (47); SE = stem exclusion 2nd-growth (6); CL = closed-canopy 2nd-growth (26); OC = open-canopy old-growth (77); CO = coarse-canopy old-growth (118); RS = riparian Spruce old-growth (5); and NF = non-forest (29).

	SS	TT	TS	SE	CL	OC	CO	RS	NF
Available shrubs (%)	41.4	60.1	39.9	2.4	2.8	39.7	29.1	27.8	17.7
	(2.4)	(4.0)	(3.1)	(1.1)	(1.0)	(2.0)	(1.7)	(10.9)	(3.7)
Vaccinium parvifolium (%)	1.1	7.5	1.4	0.0	0.1	1.1	1.5	0.3	0.1
	(0.3)	(2.8)	(0.3)	(0.0)	(0.0)	(0.2)	(0.3)	(0.3)	(0.1)
V. alaskensis/ovalifolium (%)	38.0	34.2	20.6	1.4	1.4	21.5	25.7	16.7	8.3
	(2.6)	(4.7)	(2.7)	(0.7)	(0.5)	(2.1)	(1.7)	(10.5)	(1.9)
Gaultheria shallon (%)	0.0	0.0	0.0	0.0	0.0	14.3	0.5	0.0	3.4
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(2.0)	(0.0)	(0.0)	(1.5)
Rubus spectabilis (%)	0.7	21.4	13.3	1.8	0.1	0.0	0.2	0.0	0.1
	(0.2)	(3.8)	(2.3)	(1.8)	(0.1)	(0.0)	(0.1)	(0.0)	(0.1)
Oplopanax horridus (%)	0.2	3.8	3.1	0.3	0.1	0.1	1.0	20.2	0.0
	(0.1)	(1.1)	(0.7)	(0.3)	(0.1)	(0.0)	(0.4)	(12.2)	(0.0)
Menziesia ferruginea (%)	3.9	12.1	9.5	0.3	0.0	4.3	4.6	2.0	2.3
	(0.8)	(3.4)	(2.1)	(0.3)	(0.0)	(0.6)	(0.7)	(2.0)	(1.3)
Dryopteris dilatata (%)	2.6	1.0	0.8	0.0	6.8	0.2	2.6	6.0	0.0
	(0.9)	(0.5)	(0.2)	(0.0)	(1.2)	(0.1)	(0.8)	(4.0)	(0.0)
Lysichiton americanum (%)	0.2	5.8	0.1	0.0	0.0	6.3	1.8	6.0	2.7
	(0.1)	(3.3)	(0.1)	(0.0)	(0.0)	(1.0)	(0.5)	(6.0)	(1.4)
Evergreen forbs (%)	27.0	15.6	6.4	0.0	1.2	15.3	9.8	5.3	8.8
	(2.1)	(4.4)	(1.4)	(0.0)	(0.9)	(1.6)	(1.1)	(4.6)	(1.6)
Deciduous forbs (%)	5.1	6.1	2.9	0.1	0.9	11.3	5.8	7.5	15.0
	(0.8)	(1.4)	(0.6)	(0.1)	(0.7)	(1.3)	(0.7)	(4.3)	(3.4)
Evergreen forbs (kg/ha)	290.8	168.5	68.9	0.0	13.0	165.1	105.3	57.1	94.6
	(23.0)	(47.0)	(14.9)	(0.0)	(9.6)	(16.9)	(11.9)	(49.7)	(16.9)
Deciduous forbs (kg/ha)	7.6	8.6	3.9	0.1	1.4	19.9	9.0	12.1	32.0
	(1.3)	(2.2)	(0.9)	(0.1)	(1.2)	(2.8)	(1.3)	(7.7)	(8.3)
Vaccinium spp. shrubs (kg/ha)	67.0	71.7	37.8	2.4	2.4	38.8	46.8	29.2	14.5
	(4.5)	(10.3)	(4.8)	(1.3)	(0.9)	(3.7)	(3.1)	(17.8)	(3.3)
Visibility distance (m)	10.7	11.1	10.6	17.5	29.0	16.7	16.4	13.4	30.8
	(0.1)	(3.0)	(0.6)	(2.4)	(3.0)	(0.9)	(0.8)	(1.8)	(3.0)

The understory biomass and composition data presented here will make it possible to improve the accuracy of projections of carrying capacity for deer in the Tongass National Forest. Using current GIS resource inventories, sufficient information to classify most stands in the coastal temperate rainforest of Alaska is readily available. For wildlife managers, the

TABLE 3. Overstory and environmental characteristics, $\bar{X}$ ($s_{\bar{x}}$), of deer cover types in southeastern Alaska. Abbreviations and sample sizes are the same as in Table 2.

	SS	TT	TS	SE	CL	OC	CO	RS	NF
Elevation (m)	172.3	51.8	92.5	77.2	45.3	136.0	29.1	147.2	303.5
	(11.9)	(14.5)	(8.8)	(4.8)	(3.9)	(12.1)	(1.7)	(47.1)	(52.4)
Basal area (m^2/ha)	0.0	0.0	2.3	11.6	53.3	24.7	45.6	55.4	3.6
	(0.0)	(0.0)	(1.5)	(8.0)	(4.0)	(1.0)	(1.5)	(3.7)	(1.6)
Tree height (m)	3.2	10.0	2.7	13.7	26.6	14.8	27.1	37.7	4.6
	(0.7)	(1.1)	(0.9)	(1.3)	(1.7)	(0.3)	(0.7)	(1.1)	(1.6)
Timber volume (m^3/ha)	0.0	0.0	0.0	22.7	182.6	36.9	156.8	327.8	0.0
	(0.0)	(0.0)	(0.0)	(16.6)	(18.7)	(1.7)	(7.3)	(6.4)	(0.0)
Tsuga heterophylla (%)[1]	71.5	9.5	69.8	14.8	47.6	41.8	62.8	69.9	45.6
	(16.1)	(4.9)	(23.1)	(5.2)	(5.8)	(2.7)	(2.1)	(9.2)	(9.5)
Picea sitchensis (%)	6.7	62.7	4.9	85.2	52.4	6.2	13.3	30.1	4.1
	(6.7)	(31.6)	(4.9)	(5.2)	(5.8)	(1.4)	(1.3)	(9.2)	(2.3)

[1] Percent of trees in basal area count composed of indicated species.

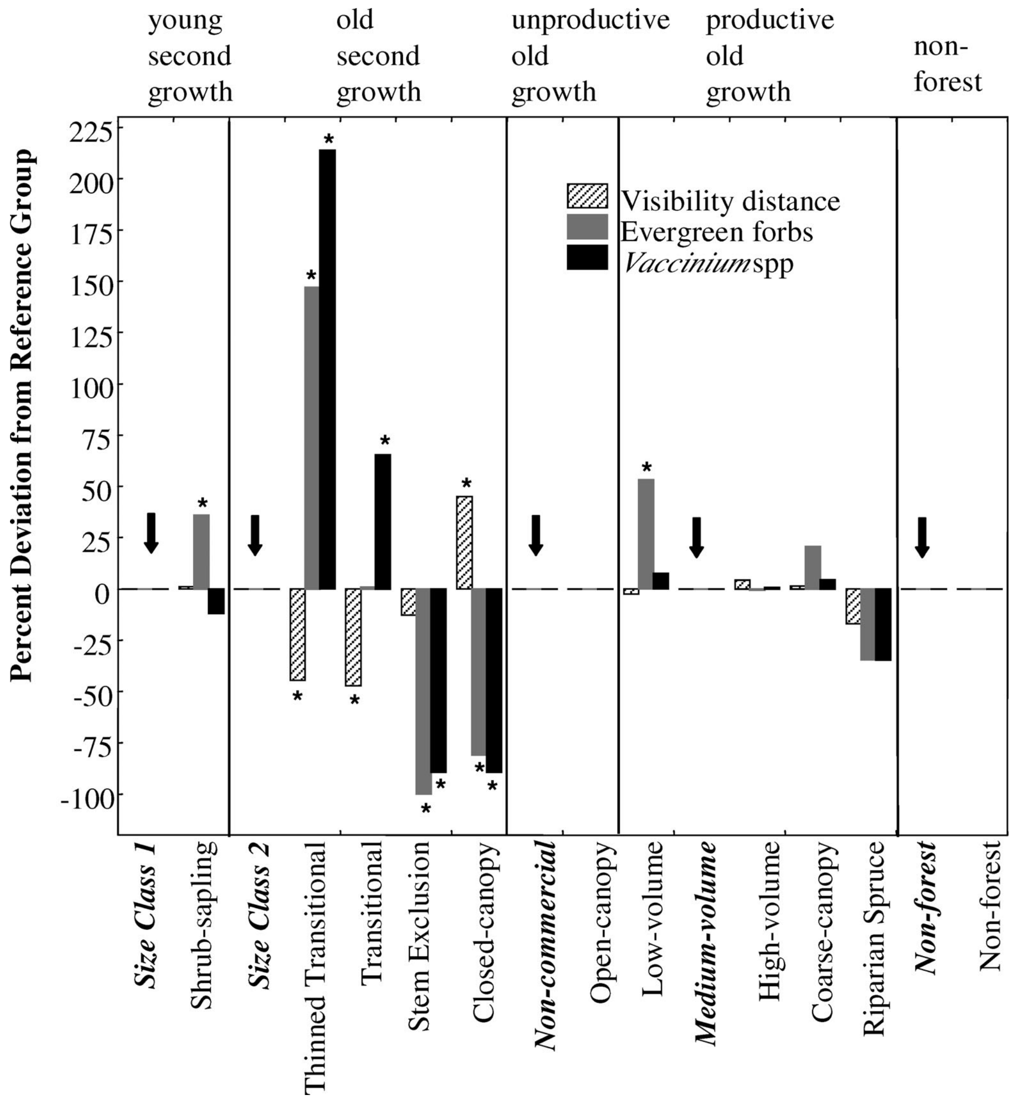

FIGURE 3. Percent deviations between existing timber-type categories and deer cover types for 3 understory variables. Titles above sections of the graph denote broad cover types within which structural and ecological categories are grouped based on age or timber volume ranges. Within each broad cover type, bold arrows and italics indicate the structural category used as a reference group. Asterisks indicate deviations >1 SE.

major advantage of these over strictly timber-driven (forest structure) categories is that they are derived from careful consideration of important deer habitat variables. Thus, our categories provide for a linkage of remotely sensed stand information with measurements of important understory characteristics that are not included in current resource inventories.

Such an integration of information is important in any regional conservation planning, which by its scale alone forces the use of remotely sensed data. The technique we have described can be applied to any animal species provided information is available regarding (1) the abundance and distribution of habitat variables that are important to the ecology of that animal and (2) 1 or more measurable variables that can be remotely sensed and exist in a resource management database. By retaining data that can be remotely sensed at the beginning of the analysis, resource managers can

TABLE 4. Comparison of deer cover types and USDA Forest Service timber types for southeastern Alaska. In most cases, age or timber-volume break points differ between the 2 systems of classification.

Deer cover type	Characteristics	Timber type	Definition
Shrub-sapling 2nd-growth	5 to 19 y post-logging	size class X (unstocked)	0 to 5 y post-logging
Thinned transitional 2nd-growth	transitional stands thinned about 20 y post-logging	size class 1 (shrub-sapling)	6 to 25 y post-logging
Transitional 2nd-growth	25 to 39 y post-logging	size class 2 (pole)	26 to 75 y post-logging
Stem exclusion 2nd-growth	40 to >44 y post-logging	size class 2 (pole)	26 to 75 y post-logging
Closed-canopy 2nd-growth	>60 y post-logging	size class 3 (sawtimber)	76 to 150 y post-logging
Open-canopy old-growth	timber volume <58.3 m^3/ha	non-commercial old-growth	timber volume <58.3 m^3/ha
Coarse-canopy old-growth	timber volume 58.3 to >408 m^3/ha	low volume old-growth and medium volume old-growth	timber volume 58.3 to 174.9 m^3/ha
Riparian Spruce old-growth	Spruce-Hemlock old-growth, timber volume 291.5 to 344 m^3/ha	high volume old-growth	timber volume >174.9 m^3/ha
Non-forest	timber volume 0 m^3/ha	non-forest	<10% canopy cover

link ecologically meaningful habitat typologies for any faunal species to resource databases. As habitat management becomes increasingly dominated by the use of GIS, the ability to integrate ecologically based habitat categories with resource categories that are distinct and amenable to remote sensing will gain importance.

Acknowledgments

We thank the numerous field technicians whose volunteer efforts produced data for this study. We also thank S Creel, G Farmer, D Person, and W Shields for discussions regarding data analysis and interpretation, and G Baldassarre, T Kunley, S McNay, and H Underwood for review comments that improved the draft manuscript. This study was funded by grants from the Edna B Sussman Fund and the Alaska Department of Fish & Game (Federal Aid in Wildlife Restoration grant W-27–2).

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Submitted 8 June 2006, accepted 27 December 2006. Corresponding Editor: C Apps.

* Unpublished report

APPENDIX

Descriptions of forest cover types in southeastern Alaska identified by cluster analysis (weighted pair-group using arithmetic averages) on 12 understory and 2 overstory (tree height, basal area) variables.

Non-forest—predominantly heath or bog-like muskegs with ≤10% canopy cover and no measurable timber volume.
Cedar-Hemlock-Salal old-growth—primarily uneven aged Cedar-Hemlock forest <58.3 m^3/ha gross timber volume; Salal dominant in understory.
Open-canopy Hemlock-Cedar-Salal old-growth—primarily uneven-aged Hemlock-Cedar forest, 58 to 116 m^3/ha gross timber volume; Salal present in understory.
Cedar-Hemlock old-growth—primarily uneven-aged Cedar-Hemlock forest, 117 to 174 m^3/ha gross timber volume.
Hemlock-Cedar old-growth—primarily uneven-aged Hemlock-Cedar forest, 175 to 232 m^3/ha gross timber volume; high forb abundance in understory.
Medium volume Hemlock-Spruce-Cedar old-growth—primarily uneven-aged Hemlock-Spruce forest, 233 to 291 m^3/ha gross timber volume; Blueberry dominant in understory.
High volume Hemlock-Spruce old-growth—primarily uneven-aged Hemlock-Spruce forest, 350 to 407 m^3/ha gross timber volume; Blueberry dominant in understory.
Very high volume Hemlock-Spruce old-growth—primarily uneven-aged Hemlock-Spruce forest, ≥408 m^3/ha gross timber volume; low abundance of shrubs and forbs in understory.
Riparian high volume old-growth—relatively small stands of Spruce-Hemlock forest 291.5 to 349.8 m^2/ha gross timber volume; situated on productive alluvial soils associated with riparian zones; relatively closed canopy resulted in less developed understory than Hemlock-Spruce old-growth.
Shrub-sapling clearcut—even-aged clearcuts ≤19 y post logging at mid-point (1998) of our study; canopy completely removed; conifer regeneration at seedling to large sapling stage.
Hemlock-Cedar transitional—older shrub-sapling clearcuts 20 to 39 y post logging at mid-point (1998) of our study; conifer regeneration at large sapling stage; canopy beginning to close, reducing amount of light reaching forest floor; shrub and forb biomass patchily distributed.
Hemlock-Spruce transitional—older shrub-sapling clearcuts 20 to 39 y post logging at mid-point (1998) of our study; conifer regeneration at large sapling stage; canopy beginning to close reducing amount of light reaching forest floor; shrub and forb biomass patchily distributed.
Thinned transitional—-transitional clearcuts silviculturally thinned approximately 10 y prior to sampling; canopy more open than transitional 2nd-growth, resulting in increased shrub growth.
Pole Spruce stem exclusion—Spruce-dominated clearcuts, 40 to 44 y post logging at the mid-point (1998) of our study; dense canopy greatly reducing transmission of light to forest floor, resulting in depauperate understory.
Closed-canopy Hemlock 2nd-growth—Hemlock-Spruce-dominated clearcuts, 45 to >70 y post-logging at the mid-point (1998) of our study; beginning to self-thin; dense canopy greatly reducing transmission of light to forest floor resulting in depauperate understory.
Closed-canopy Spruce sawtimber—Spruce-dominated clearcuts, 45 to >70 y post-logging at the mid-point (1998) of our study, beginning to self-thin; dense canopy greatly reducing transmission of light to forest floor; basal area of dominant trees similar to highest volume old-growth categories.